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Nair et al.

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(54) **TIMING SYNCHRONIZATION SYSTEM AND METHOD OF SUPER REGENERATIVE RECEIVER BASED ON ULTRA LOW POWER COMMUNICATION**

(71) Applicant: **Samsung Electronics Co., Ltd.**, Suwon-si (KR)

(72) Inventors: **Jinesh Parameshwaran Nair**, Bangalore (IN); **Kiran Bynam**, Bangalore (IN); **Manoj Choudhary**, Bangalore (IN); **Pradeep Dwarakanath**, Bangalore (IN); **Youngjun Hong**, Suwon-si (KR)

(73) Assignee: **Samsung Electronics Co., Ltd.**, Suwon-si (KR)

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H04B 1/30 (2006.01)
H04L 7/04 (2006.01)
H04L 25/00 (2006.01)

(52) **U.S. Cl.**

CPC ***H04B 1/30*** (2013.01); ***H04L 7/041*** (2013.01); ***H04L 25/00*** (2013.01)

(58) **Field of Classification Search**

CPC H04B 1/7183; H04B 7/2125; H04B 1/06; H03D 11/00; H04L 7/06
USPC 375/364, 138, 147, 150, 260, 267, 329, 375/343; 370/203, 350, 392, 431
See application file for complete search history.

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Primary Examiner — Dhaval Patel
(74) *Attorney, Agent, or Firm* — NSIP Law

(57) **ABSTRACT**

A method and apparatus are provided to generate a preamble signal. A peak of each pulse of the preamble signal is synchronized with a sensitivity region of a super regenerative receiver (SRR). The method and apparatus are configured to transmit, to the SRR, a data packet comprising the preamble signal, wherein the data packet is a baseband signal corresponding to the preamble signal.

20 Claims, 10 Drawing Sheets

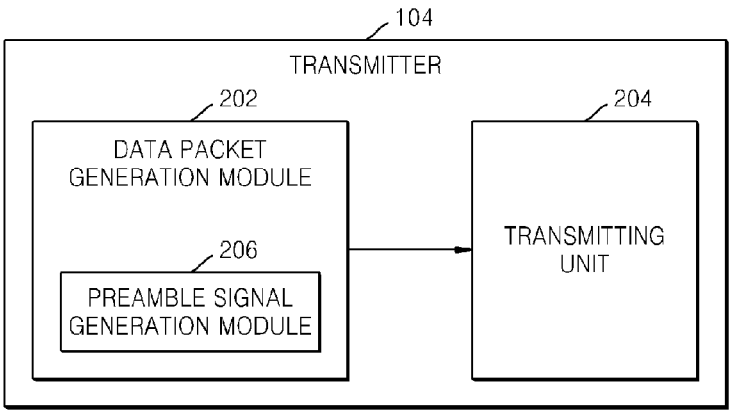


FIG. 1

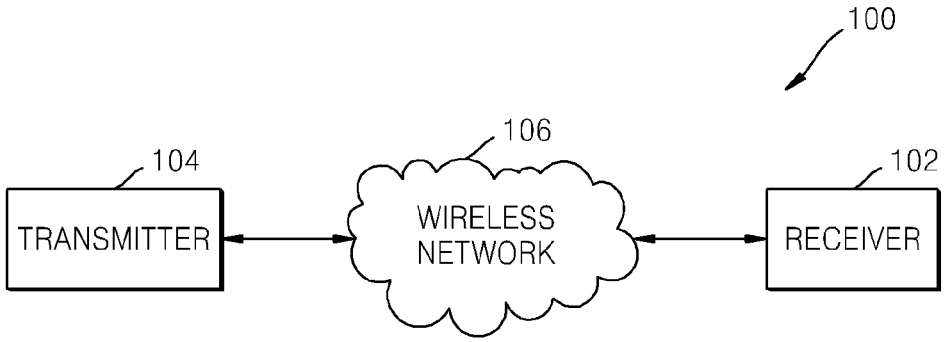

100
106
104
102
TRANSMITTER
WIRELESS NETWORK
RECEIVER

FIG. 2

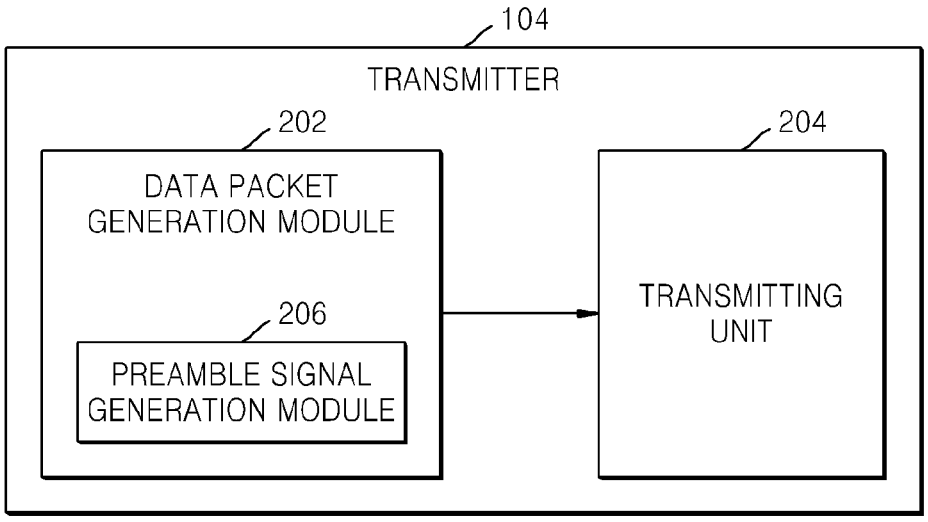

104
TRANSMITTER
202
DATA PACKET GENERATION MODULE
206
PREAMBLE SIGNAL GENERATION MODULE
204
TRANSMITTING UNIT

FIG. 3

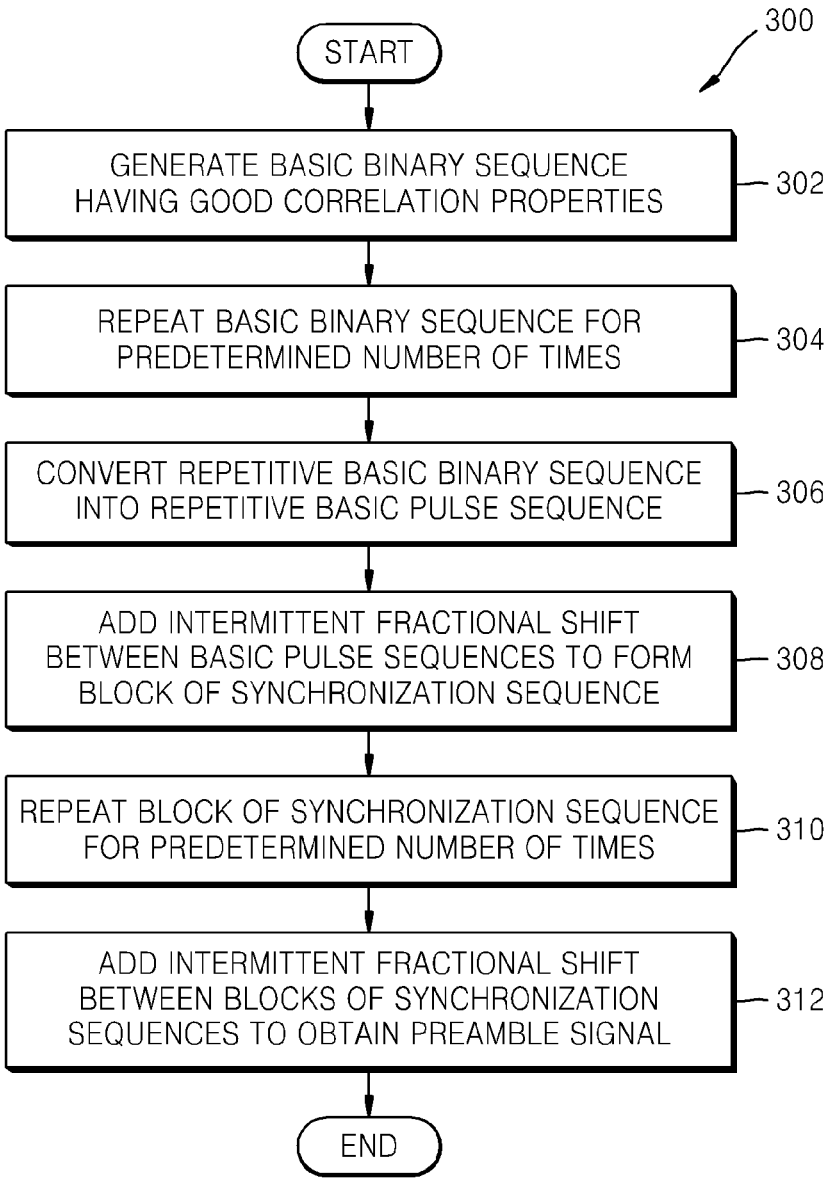

300
START
GENERATE BASIC BINARY SEQUENCE HAVING GOOD CORRELATION PROPERTIES
302
REPEAT BASIC BINARY SEQUENCE FOR PREDETERMINED NUMBER OF TIMES
304
CONVERT REPETITIVE BASIC BINARY SEQUENCE INTO REPETITIVE BASIC PULSE SEQUENCE
306
ADD INTERMITTENT FRACTIONAL SHIFT BETWEEN BASIC PULSE SEQUENCES TO FORM BLOCK OF SYNCHRONIZATION SEQUENCE
308
REPEAT BLOCK OF SYNCHRONIZATION SEQUENCE FOR PREDETERMINED NUMBER OF TIMES
310
ADD INTERMITTENT FRACTIONAL SHIFT BETWEEN BLOCKS OF SYNCHRONIZATION SEQUENCES TO OBTAIN PREAMBLE SIGNAL
312
END

FIG. 4

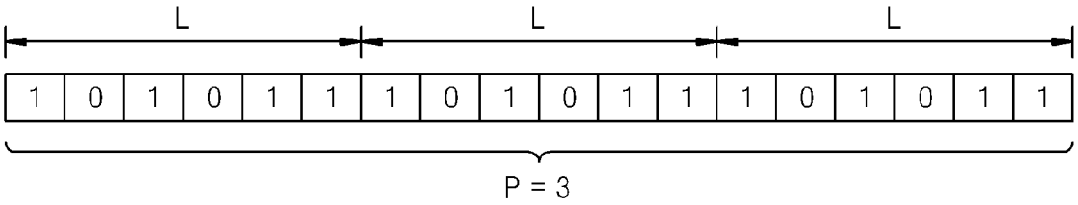


FIG. 5

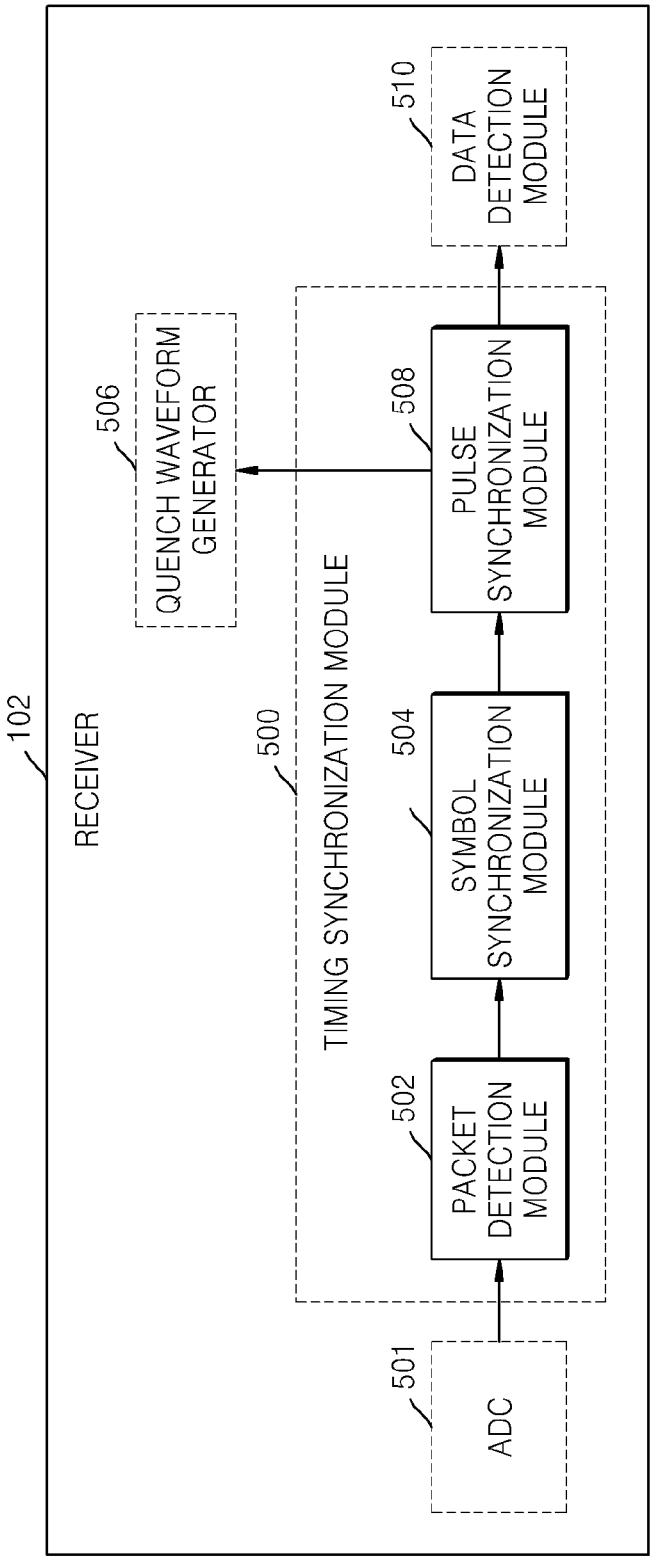

102
RECEIVER
500
TIMING SYNCHRONIZATION MODULE
501
ADC
502
PACKET DETECTION MODULE
504
SYMBOL SYNCHRONIZATION MODULE
506
QUENCH WAVEFORM GENERATOR
508
PULSE SYNCHRONIZATION MODULE
510
DATA DETECTION MODULE

FIG. 6

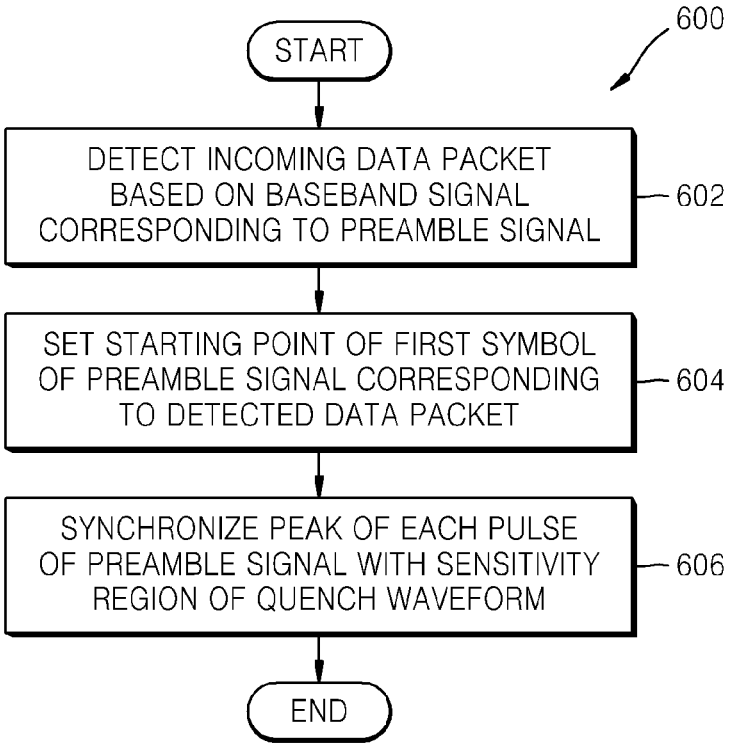

600
START
DETECT INCOMING DATA PACKET BASED ON BASEBAND SIGNAL CORRESPONDING TO PREAMBLE SIGNAL
602
SET STARTING POINT OF FIRST SYMBOL OF PREAMBLE SIGNAL CORRESPONDING TO DETECTED DATA PACKET
604
SYNCHRONIZE PEAK OF EACH PULSE OF PREAMBLE SIGNAL WITH SENSITIVITY REGION OF QUENCH WAVEFORM
606
END

FIG. 7

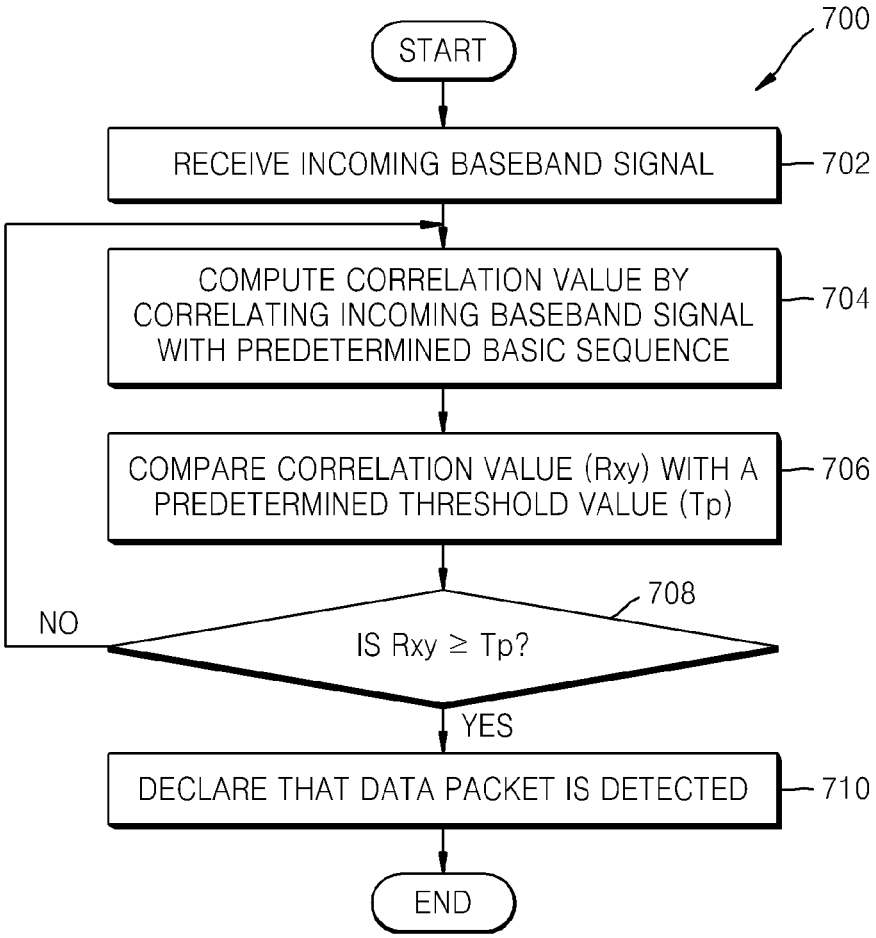

700
START
RECEIVE INCOMING BASEBAND SIGNAL
702
COMPUTE CORRELATION VALUE BY CORRELATING INCOMING BASEBAND SIGNAL WITH PREDETERMINED BASIC SEQUENCE
704
COMPARE CORRELATION VALUE (Rxy) WITH A PREDETERMINED THRESHOLD VALUE (Tp)
706
708
IS Rxy ≥ Tp?
NO
YES
DECLARE THAT DATA PACKET IS DETECTED
710
END

FIG. 8

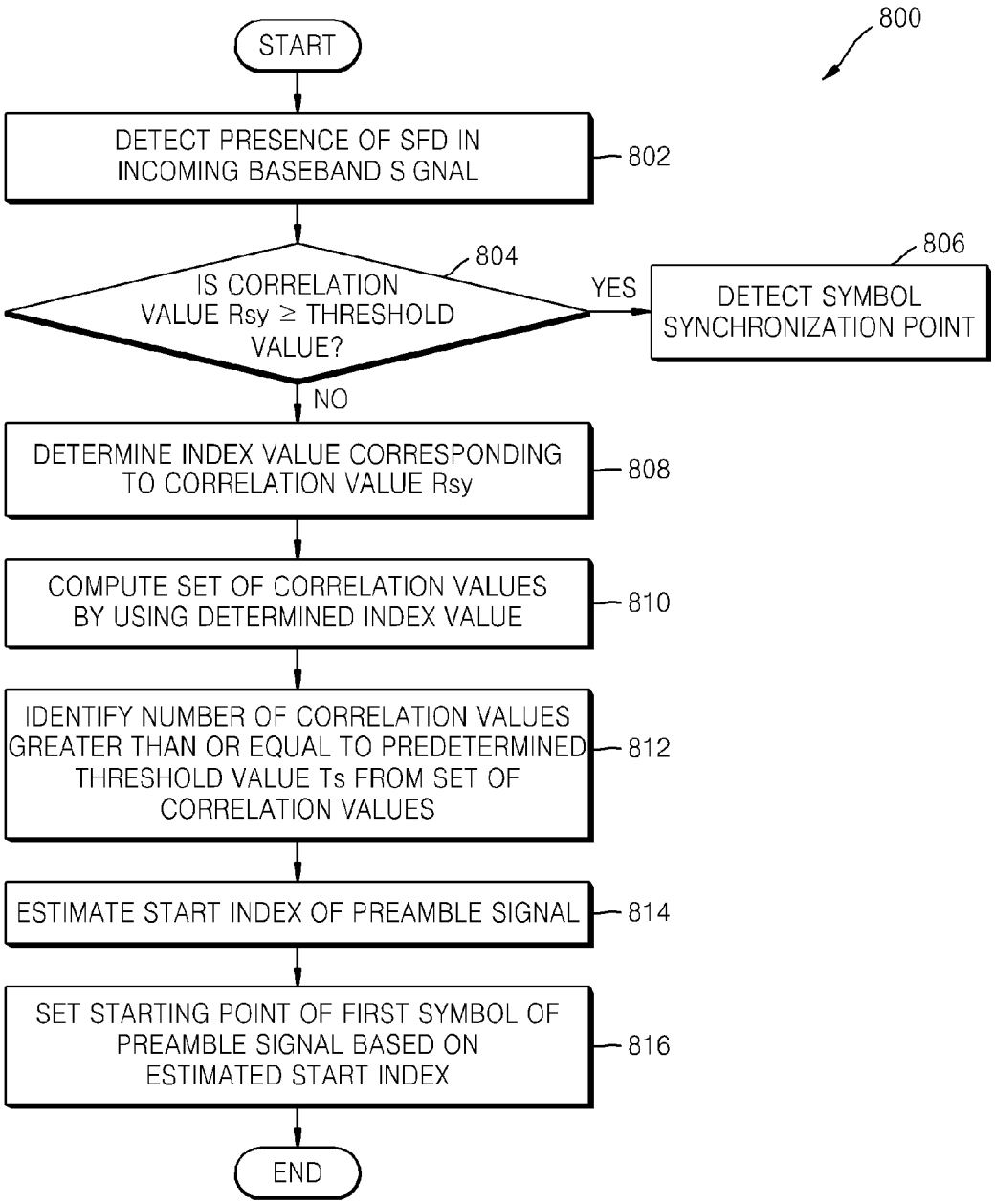

800
START
DETECT PRESENCE OF SFD IN INCOMING BASEBAND SIGNAL
802
IS CORRELATION VALUE Rsy ≥ THRESHOLD VALUE?
804
YES
DETECT SYMBOL SYNCHRONIZATION POINT
806
NO
DETERMINE INDEX VALUE CORRESPONDING TO CORRELATION VALUE Rsy
808
COMPUTE SET OF CORRELATION VALUES BY USING DETERMINED INDEX VALUE
810
IDENTIFY NUMBER OF CORRELATION VALUES GREATER THAN OR EQUAL TO PREDETERMINED THRESHOLD VALUE Ts FROM SET OF CORRELATION VALUES
812
ESTIMATE START INDEX OF PREAMBLE SIGNAL
814
SET STARTING POINT OF FIRST SYMBOL OF PREAMBLE SIGNAL BASED ON ESTIMATED START INDEX
816
END

FIG. 9

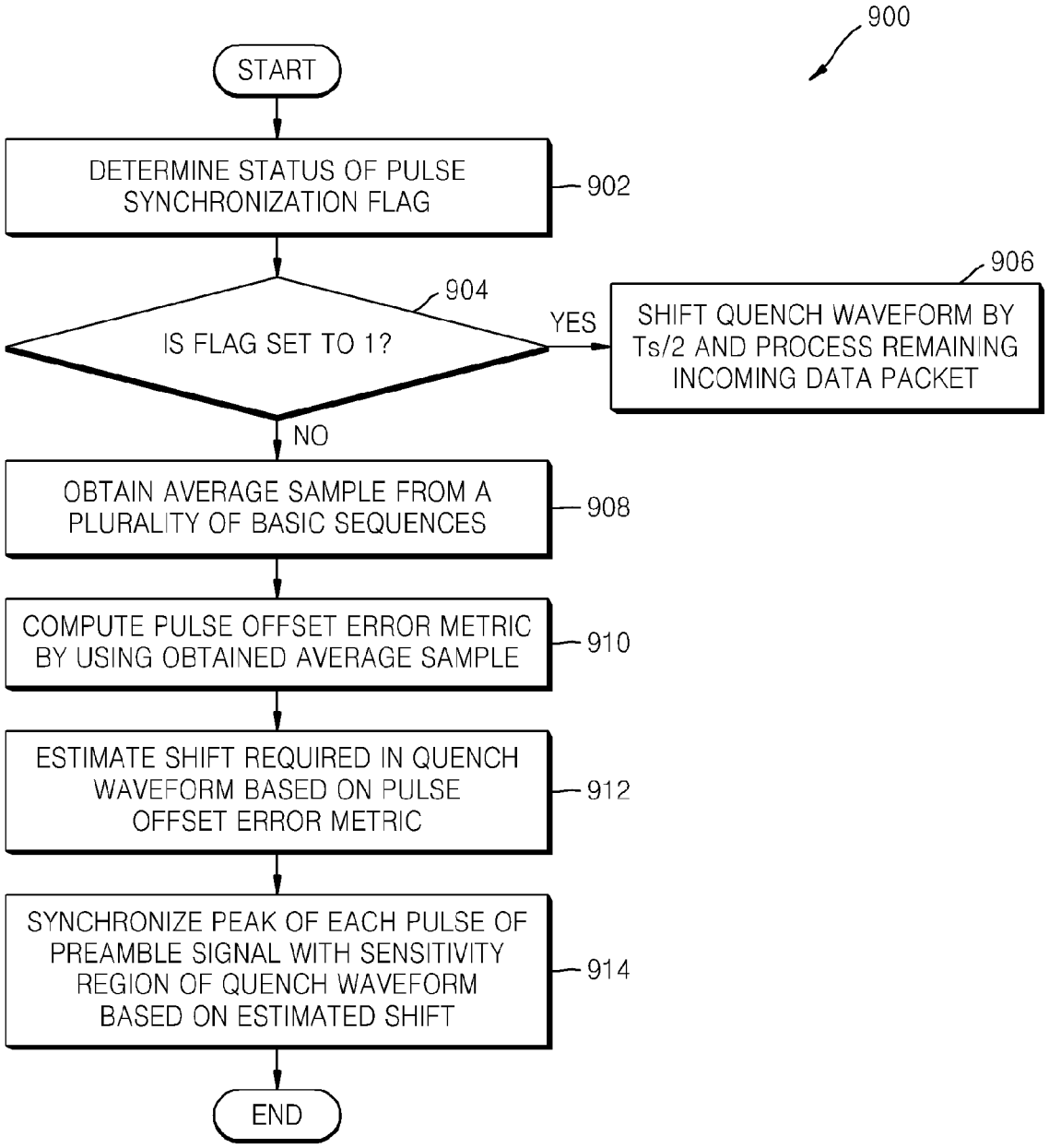

900
START
DETERMINE STATUS OF PULSE SYNCHRONIZATION FLAG
902
IS FLAG SET TO 1?
904
YES
SHIFT QUENCH WAVEFORM BY Ts/2 AND PROCESS REMAINING INCOMING DATA PACKET
906
NO
OBTAIN AVERAGE SAMPLE FROM A PLURALITY OF BASIC SEQUENCES
908
COMPUTE PULSE OFFSET ERROR METRIC BY USING OBTAINED AVERAGE SAMPLE
910
ESTIMATE SHIFT REQUIRED IN QUENCH WAVEFORM BASED ON PULSE OFFSET ERROR METRIC
912
SYNCHRONIZE PEAK OF EACH PULSE OF PREAMBLE SIGNAL WITH SENSITIVITY REGION OF QUENCH WAVEFORM BASED ON ESTIMATED SHIFT
914
END

FIG. 10A

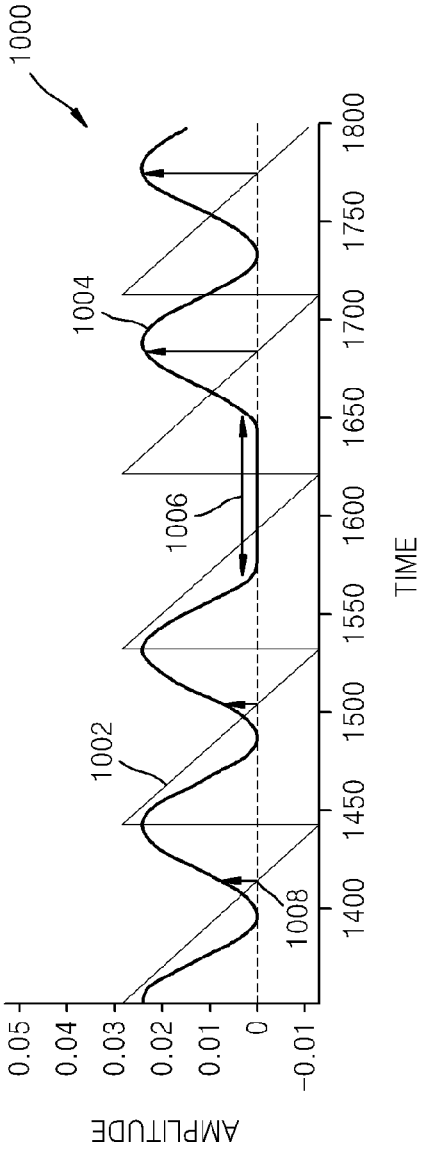
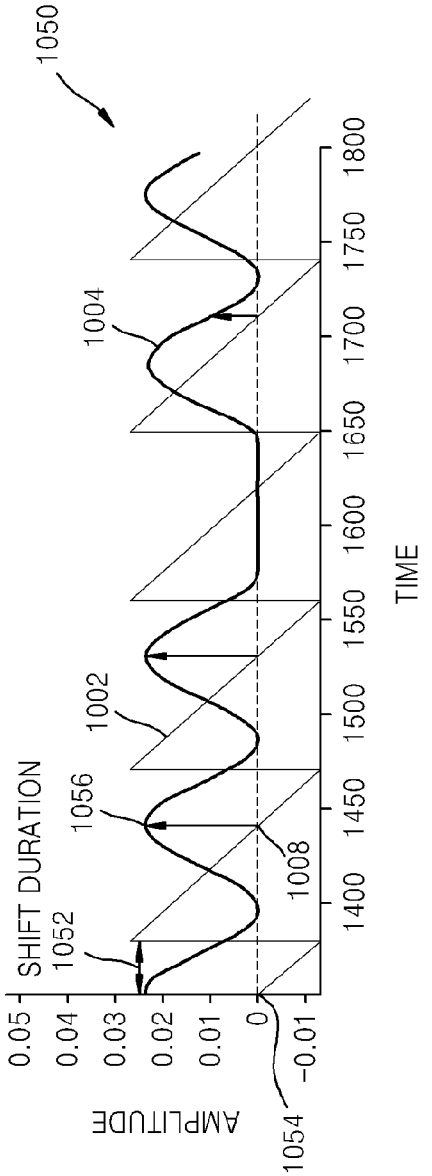


FIG. 10B



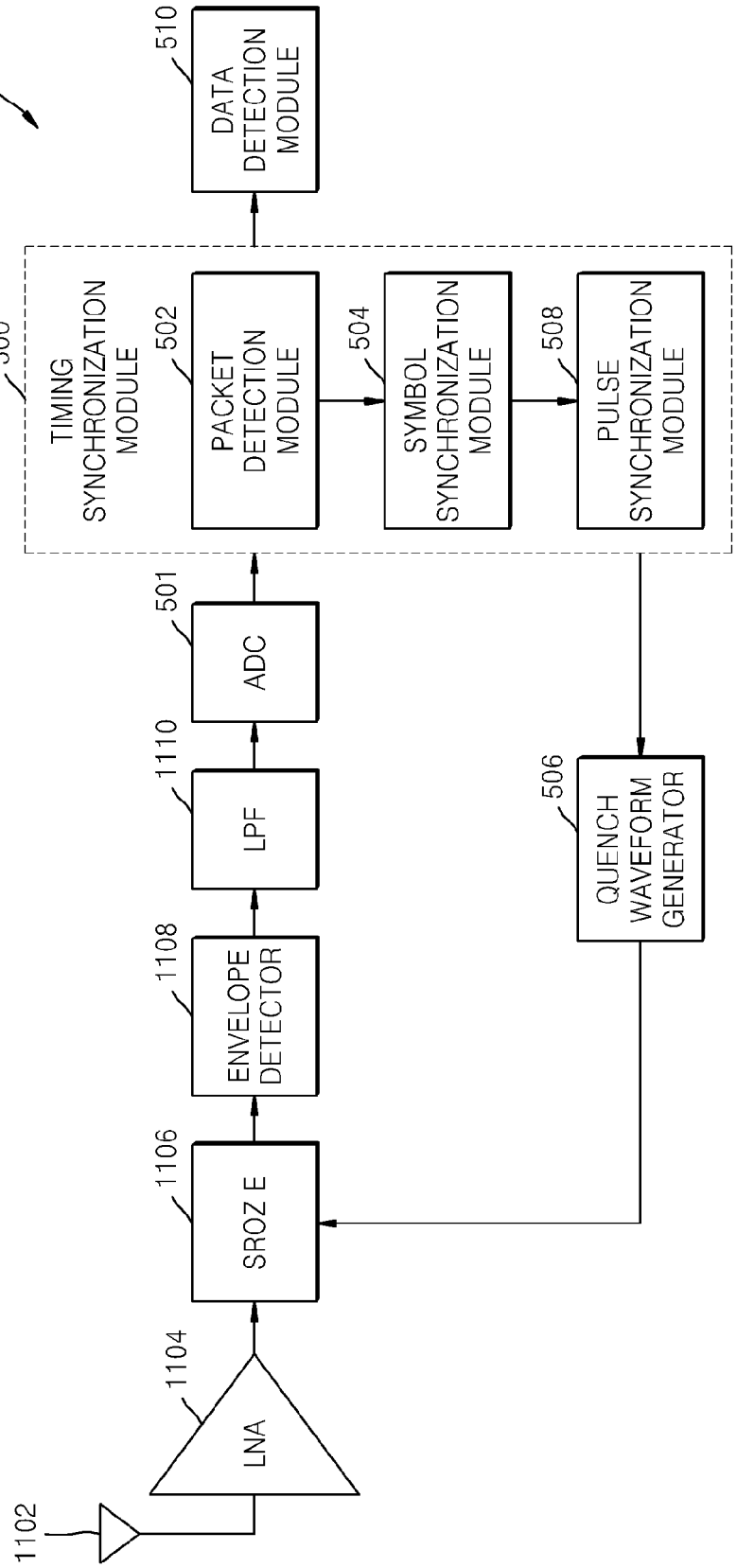

1100
510
DATA DETECTION MODULE
500
TIMING SYNCHRONIZATION MODULE
502
PACKET DETECTION MODULE
504
SYMBOL SYNCHRONIZATION MODULE
508
PULSE SYNCHRONIZATION MODULE
501
ADC
1110
LPF
1108
ENVELOPE DETECTOR
1106
SROZ E
1104
LNA
1102
506
QUENCH WAVEFORM GENERATOR

FIG. 11

TIMING SYNCHRONIZATION SYSTEM AND METHOD OF SUPER REGENERATIVE RECEIVER BASED ON ULTRA LOW POWER COMMUNICATION

RELATED APPLICATIONS

This application claims the benefit of Indian Patent Application No. 3564/CHE/2013, filed on Aug. 9, 2013, and Korean Patent Application No. 10-2014-0057951, filed on May 14, 2014, in the Korean Intellectual Property Office, the disclosures of which are incorporated herein by reference in their entirety.

BACKGROUND

1. Field

The following description relates to a field of communication systems, and more particularly, to timing synchronization in a wireless communication system.

2. Description of Related Art

Receivers, such as a super regenerative receiver (SRR), are ultra low power radio receivers for low data rate applications. A basic structure of the SRR includes an antenna, a low noise amplifier (LNA), a super regenerative oscillator (SRO), an envelope detector (ED), an automatic gain control (AGC), a quench waveform generator, and a baseband filter (BBF). The operation principle of the SRR is based on a repeated build-up and decay of self-generated oscillations in the SRO having a frequency near radio frequency (RF) signal frequency intercepted by the antenna. The SRR is typically used in low power body area networks, remote control systems, such as garage door openers, robots, model ships, airplanes, short distance telemetry, and wireless security.

In general, frequency selectivity of the SRR is directly affected by an over quenching rate (OQR) of a quench signal. Currently, each data symbol is oversampled by a quench signal operating at a quench rate considerably higher than a data rate. This translates into relatively low frequency selectivity and an equivalent noise bandwidth that is much larger than the signal bandwidth. Thus, the SRR may be easily affected by out-of-band interference. Hence, it is desirable to maintain the OQR as low as possible. However, a higher OQR is needed to ensure that outputs are obtained for each incoming pulse envelope in the SRR. From these outputs, a fractional sample rate is chosen to maximize overall energy capture of an incoming signal. In order to improve an interference rejection, a lower OQR is required, but a higher OQR is necessary to improve the synchronization performance of the SRR.

SUMMARY

This Summary is provided to introduce a selection of concepts in a simplified form that are further described below in the Detailed Description. This Summary is not intended to identify key features or essential features of the claimed subject matter, nor is it intended to be used as an aid in determining the scope of the claimed subject matter.

In accordance with an example, there is provided a method, including generating a preamble signal, wherein a peak of each pulse of the preamble signal is synchronized with a sensitivity region of a super regenerative receiver (SRR); and transmitting, to the SRR, a data packet including the preamble signal, wherein the data packet is a baseband signal corresponding to the preamble signal.

The generating of the preamble signal may include generating a basic binary sequence, repeating the generated basic binary sequence for a number of times, converting the repetitive basic binary sequences into repetitive basic pulse sequences, adding a first intermittent fractional shift between basic pulse sequences to obtain a block of synchronization sequence, repeating the block of synchronization sequences for a number of times, and adding a second intermittent fractional shift between blocks of synchronization sequences.

In accordance with another illustrative example, there is provided a method of a super regenerative receiver (SRR), the method includes detecting a data packet based on a baseband signal corresponding to a preamble signal received from a transmitter; setting a starting point of a first symbol of the preamble signal corresponding to the detected data packet; and synchronizing a peak of each pulse of the preamble signal with a sensitivity region of the SRR based on the starting point of the first symbol of the preamble signal corresponding to the data packet.

The detecting of the incoming data packet may include computing a correlation value by correlating the baseband signal with a basic sequence, comparing the computed correlation value and a threshold value and outputting a comparison result, and detecting the incoming data packet based on the comparison result.

The computing of the correlation value may include computing a correlation value for each period in a basic sequence of the preamble signal, and computing an average correlation value by averaging the computed correlation values corresponding to the periods in the basic sequence.

The setting of the starting point may include detecting a start frame delimiter (SFD) sequence of the baseband signal by computing a correlation value between the baseband signal and a SFD sequence, and determining a symbol synchronization point by comparing the computed correlation value and a threshold value.

The setting of the starting point further may include determining, according to a comparison between the computed correlation value and the threshold value, an index value corresponding to a correlation value obtained by correlating the baseband signal with a basic sequence, computing a set of correlation values using the index value, identifying, from the computed set of correlation values, a correlation value that is greater than or equal to a threshold value, and estimating a start index of the preamble signal based on a number of identified correlation values, wherein the starting point of the first symbol of the preamble signal is set based on the estimated start index.

The synchronizing of the peak of each pulse of the preamble signal may include determining a status of a pulse synchronization flag, and processing, based on the status of the pulse synchronization flag, the data packet remaining after shifting a quench waveform by a period.

The synchronizing of the peak of each pulse of the preamble signal may also include obtaining an average sample for each of basic sequences of the preamble signal based on the status of the pulse synchronization flag, computing a pulse offset error metric using the obtained average samples, and estimating, based on the computed pulse offset error metric, a shift required in the quench waveform with respect to a start index of the preamble signal in order to synchronize the peak of each pulse of the preamble signal with the sensitivity region of the SRR, wherein the peak of each pulse of the preamble signal is synchronized with the sensitivity region of the SRR based on the estimated shift.

The synchronizing of the peak of each pulse of the preamble signal may include identifying an index corresponding

to a maximum correlation value from among the identified correlation values, and estimating, based on the identified index, a shift required in a quench waveform with respect to a start index of the preamble signal in order to synchronize the peak of each pulse of the preamble signal with the sensitivity region of the SRR, wherein the peak of each pulse of the preamble signal is synchronized with the sensitivity region of the SRR based on the estimated shift.

In accordance with an example, there is provided an apparatus, including a preamble signal generation module configured to generate a preamble signal, wherein a peak of each pulse of the preamble signal is synchronized with a sensitivity region of a super regenerative receiver (SRR); and a transmitter configured to transmit, to the SRR, a data packet that includes the preamble signal and is in a form of a baseband signal corresponding to the generated preamble signal.

The preamble signal may include a block of synchronization sequence, wherein the block of synchronization sequence includes basic sequences with an intermittent fractional shift of a time duration between consecutive basic sequences, and wherein each of the basic sequences has a length and includes a period.

The preamble signal generation module may be configured to: generate a basic binary sequence, repeat the basic binary sequence for a number of times, convert the repetitive basic binary sequences into repetitive basic pulse sequences, add a first intermittent fractional shift between basic pulse sequences to obtain a block of synchronization sequences, repeat the block of synchronization sequences for a number of times, and add a second intermittent fractional shift between blocks of synchronization sequences.

In accordance with an example, there is provided super regenerative receiver (SRR), including a packet detection module configured to detect a data packet based on a baseband signal corresponding to a preamble signal received; a symbol synchronization module configured to set a starting point of a first symbol of the preamble signal corresponding to the detected data packet; and a pulse synchronization module configured to synchronize a peak of each pulse of the preamble signal with a sensitivity region of the SRR based on the starting point of the first symbol of the preamble signal corresponding to the data packet.

The packet detection module may be configured to: compute a correlation value by correlating the baseband signal with a basic sequence, compare the computed correlation value and a threshold value, and detect the data packet based on a comparison result.

The packet detection module may be configured to: compute a correlation value for each period in a basic sequence of the preamble signal, and compute an average correlation value by averaging the computed correlation values corresponding to the periods in the basic sequence.

The symbol synchronization module may be configured to: detect a start frame delimiter (SFD) sequence of the baseband signal by computing a correlation value between the baseband signal and a SFD sequence, and determine a symbol synchronization point by comparing the correlation value and a threshold value.

The symbol synchronization module may be configured to: determine, according to a comparison between the computed correlation value and the predetermined threshold value, an index value corresponding to a correlation value obtained by correlating the baseband signal with a basic sequence, compute a set of correlation values by using the index value, identify, from the set of correlation values, a correlation value that is greater than or equal to a threshold value, estimate a start index of the preamble signal based on a number of identified correlation values, and set the starting point of the first symbol of the preamble signal based on the estimated start index.

The pulse synchronization module may be configured to: determine a status of a pulse synchronization flag, and process, based on the status of the pulse synchronization flag, the data packet remaining after shifting a quench waveform by a period.

The pulse synchronization module may be configured to: obtain an average sample for each of basic sequences of the preamble signal based on the status of the pulse synchronization flag, compute a pulse offset error metric by using the obtained average samples, estimate, based on the computed pulse offset error metric, a shift required in the quench waveform with respect to a start index of the preamble signal in order to synchronize the peak of each pulse of the preamble signal with the sensitivity region of the SRR, and synchronize the peak of each pulse of the preamble signal with the sensitivity region of the SRR based on the estimated shift.

The pulse synchronization module may be configured to: identify an index corresponding to a maximum correlation value from among the identified correlation values, estimate, based on the identified index, a shift required in a quench waveform with respect to a start index of the preamble signal in order to synchronize the peak of each pulse of the preamble signal with the sensitivity region of the SRR, and synchronize the peak of each pulse of the preamble signal with the sensitivity region of the SRR based on the estimated shift.

Other features and aspects may be apparent from the following detailed description, the drawings, and the claims.

BRIEF DESCRIPTION OF THE DRAWINGS

These and/or other aspects will become apparent and more readily appreciated from the following description of the embodiments, taken in conjunction with the accompanying drawings in which:

FIG. **1** is a block diagram of a wireless communication system, according to an embodiment;

FIG. **2** is a block diagram of a transmitter of FIG. **1**, according to an embodiment;

FIG. **3** is a flowchart of an exemplary method of generating a preamble signal, according to an embodiment;

FIG. **4** is a diagram of an exemplary basic binary sequence used for generating the preamble signal;

FIG. **5** is a block diagram of a receiver of FIG. **1**, according to an embodiment;

FIG. **6** is a flowchart of an exemplary method of timing synchronization in a receiver, according to an embodiment;

FIG. **7** is a flowchart of an exemplary method of detecting an incoming data packet based on a baseband signal, according to an embodiment;

FIG. **8** is a flowchart of an exemplary method of setting a starting point of a preamble signal corresponding to a detected data packet, according to an embodiment;

FIG. **9** is a flowchart of an exemplary method of synchronizing a peak of each pulse of a preamble signal corresponding to a detected data packet within a sensitivity region of a receiver, according to an embodiment;

FIGS. **10**A and **10**B are schematic diagrams illustrating synchronization of a peak of each of a preamble signal with a sensitivity region of a super regenerative receiver (SRR); and

FIG. **11** is a block diagram of an SRR, according to an embodiment.

Throughout the drawings and the detailed description, unless otherwise described, the same drawing reference numerals will be understood to refer to the same elements,

features, and structures. The relative size and depiction of these elements may be exaggerated for clarity, illustration, and convenience.

DETAILED DESCRIPTION

The following detailed description is provided to assist the reader in gaining a comprehensive understanding of the methods, apparatuses, and/or systems described herein. Accordingly, various changes, modifications, and equivalents of the systems, apparatuses and/or methods described herein will be suggested to those of ordinary skill in the art. Also, descriptions of well-known functions and constructions may be omitted for increased clarity and conciseness. As used herein, expressions such as "at least one of," when preceding a list of elements, modify the entire list of elements and do not modify the individual elements of the list.

Reference will now be made in detail to embodiments, examples of which are illustrated in the accompanying drawings. In this regard, the embodiments may have different forms and should not be construed as being limited to the descriptions set forth herein. Elements and features that may be easily derived by one of ordinary skill in the art to which the present disclosure pertains based on the detailed description of the embodiments are within the spirit and scope of the present disclosure as defined by the appended claims

In addition, it will be understood that although the terms "first", "second", etc. may be used herein to describe various components, these components should not be limited by these terms and should not refer to a particular order or arrangement of the components. These components are only used to distinguish one component from another.

The terminology used herein is for the purpose of describing particular embodiments only and is not intended to be limiting of the present invention. As used herein, the singular forms "a," "an" and "the" are intended to include the plural forms as well, unless the context clearly indicates otherwise. It will be further understood that the terms "comprises" and/or "comprising," when used in this specification, specify the presence of stated features, integers, steps, operations, elements, and/or components, but do not preclude the presence or addition of one or more other features, integers, steps, operations, elements, components, and/or groups thereof.

Unless otherwise defined, all terms (including technical and scientific terms) used herein have the same meaning as commonly understood by one of ordinary skill in the art to which the present invention belongs. It will be further understood that terms, such as those defined in commonly used dictionaries, should be interpreted as having a meaning that is consistent with their meaning in the context of the relevant art and will not be interpreted in an idealized or overly formal sense unless expressly so defined herein.

FIG. **1** is a block diagram of a wireless communication system **100**, according to an embodiment. In FIG. **1**, the wireless communication system **100** includes a receiver **102**, a transmitter **104**, and a wireless network **106**. The transmitter **104** and the receiver **102** are wirelessly connected through the wireless network **106**. In one illustrative example, the receiver **102** is a super regenerative receiver (SRR).

In the wireless communication system **100**, the transmitter **104** generates and transmits data packets each including a preamble signal, a start frame delimiter (SFD), and data payload. The preamble signal includes blocks of synchronization sequences (also referred to as training sequences) with a first intermittent fractional shift between the consecutive blocks of synchronization sequences. Each block of synchronization sequence includes repetitive basic sequences with a second intermittent fractional shift. Further, each basic sequence includes one or more periods with good correlation properties.

The receiver **102** continuously determines a presence of data packets in the air. When the transmitter **104** transmits the preamble signal in the form of a baseband signal, the receiver **102** detects the presence of data packets in the air based on the incoming baseband signal. Once a data packet is detected, the receiver **102** determines a starting point of the preamble signal, and synchronizes a peak of each pulse of the preamble signal with a sensitivity region of the receiver **102** by shifting a quench waveform having an over quenching rate (OQR) equal to 1 with respect to the starting point of the preamble signal. A sensitivity region of the receiver **102** corresponds to a region where the regenerative gain of the SRR has a significant value. For example, the sensitivity region of the SRR is a negative slop zero crossing of the quench waveform or any other arbitrary point where the regenerative gain of the SRR is significant. Accordingly, the quench waveform is shifted such that a combination of the incoming baseband signal and the sensitivity region maximizes the regenerative gain of the SRR. Thereafter, the receiver **102** processes the remaining incoming baseband signal and proceeds with data detection.

FIG. **2** is a block diagram of the transmitter **104** of FIG. **1**, according to an embodiment. The transmitter **104** includes a data packet generation module **202** and a transmitting unit **204**. The data packet generation module **202** includes a preamble signal generation module **206**. The data packet generation module **202** is configured to generate data packets carrying data intended for the receiver **102**. Each data packet includes a preamble signal, an SFD, and payload data. The preamble signal generation module **206** is configured to generate a preamble signal. The preamble signal enables the receiver **102** to perform timing synchronization with the transmitter **104**. In order to generate the preamble signal, the preamble signal generation module **206** selects a basic binary sequence with good correlation properties. The basic binary sequence may be inherently periodic with P periods and length L. For example, the basic binary sequence is a pseudo noise sequence (PN sequence) (formed using 0s and 1s) with P periods and length L, as shown in FIG. **4**. The preamble signal generation module **206** repeats the basic binary sequence for a predetermined number of times (e.g., Q=3). The preamble signal generation module **206** converts the basic binary sequences into basic pulse sequence using a pulse shaping filter. In one exemplary implementation, the basic binary sequences are upsampled by a specific factor. Then, using a Gaussian filter or a raised cosine filter, is in the upsampled basic binary sequences are translated into discrete waveforms of a predetermined pulse shape with an associated time period T_s. Consequently, basic pulse sequences including pulses and zeros of length LPT_s with Q repetition are obtained.

Thereafter, the preamble signal generation module **206** introduces intermittent fractional shift of duration αT_s between the basic pulse sequences, where T_s is a time period of a single pulse and a value of a lies between 0 and 1. The value of 'α' is selected such that different portions of pulses in the basic pulse sequences fall within the sensitivity region of the receiver **102** during each of the basic pulse sequences. In one example, the value of α is equal to $T_s/4$. It can be noted that, the intermittent fractional shift αT_s is a fractional multiple of the time period of the single pulse. In other words, intermittent fractional shift is obtained by multiplying a value between 0 and 1 to the time period of the single pulse. For example, for repetition of binary pulse sequences (Q)=3, the preamble signal generation module **206** introduces the inter-

mittent fractional shift between a first basic pulse sequence and a second basic pulse sequence, and another intermittent fractional shift between the second basic pulse sequence and a third basic pulse sequence. Hence, when Q=3, the preamble signal generation module **206** introduces Q−1 intermittent fractional shifts. The intermittent fractional shift is introduced such that the sensitivity region of the receiver **102** occurs at different positions of pulses in different portions of the preamble signal. Also, the intermittent fractional shift is introduced such that energy capture of the receiver **102** changes for each period of the preamble signal. In this manner, the preamble signal generation module **206** generates a single block of synchronization sequence including repetitive basic pulse sequences of length LPT_S with the intermittent fractional shift αT_s between two basic pulse sequences.

In some embodiments, the preamble signal generation module **206** generates blocks of synchronization sequences with intermittent fractional shifts βT_s between the blocks of synchronization sequences such that a total sum of the fractional shifts is $(Q-1)\alpha T_s+\beta T_s(i)$, where i=1−(Z−1) is an integral multiple of the time period of a single pulse T_s. The preamble signal generation module **206** generating of the blocks of synchronization sequences ensures that each of the blocks of synchronization sequences behave in the same manner or consistently at the receiver **102** as each of corresponding portions of the blocks of synchronization sequences influences the sensitivity region of the receiver **102**. The value of β is selected such that each block of synchronization sequence has consistent characteristics as other blocks in the synchronization sequence or that each block of synchronization sequence behaves in a similar manner when passed through the receiver **102**. In one illustrative example, $\beta=T_s/2$ when Q=3 and $\alpha=T_s/4$. In another illustrative example, the value of β may range from 0 to 1.

As described above, the blocks of synchronization sequences are followed by an SFD sequence s(t). The SFD sequence is added to obtain a good estimate of a starting point of a first symbol of the preamble signal. For example, the SFD sequence is a binary sequence (e.g., 01011001) having a length of 8 or 16 with good correlation properties which is upsampled and passed through a pulse shaping filter.

Once the data packet is generated, the transmitting unit **204** transmits the data packet with the preamble signal to the receiver **102**.

FIG. **3** is a flowchart **300** of an exemplary method of generating a preamble signal, according to an embodiment. In operation **302**, the method generates a basic binary sequence with P periods and length L having good correlation properties. For example, the basic binary sequence is a PN sequence. In operation **304**, the method repeats the basic binary sequence for a predetermined number of times (Q). In operation **306**, the method converts the repetitive basic binary sequence into a repetitive basic pulse sequence with 0s and pulses using a pulse shaping filter.

In operation **308**, the method adds an intermittent fractional shift αT_s between basic pulse sequences to form a block of synchronization sequence. In operation **310**, the method repeats the block of synchronization sequence for a predetermined number of times. In operation **312**, the method adds an intermittent fractional shift βT_s between blocks of synchronization sequences to obtain a preamble signal. Operation **310** and **312** are optional. In other words, the preamble signal may include a single bock of synchronization sequence instead of blocks of synchronization sequences.

FIG. **5** is a block diagram of a receiver of FIG. **1**, according to an embodiment. The receiver **102** includes an analog-to-digital converter (ADC) **501**, a timing synchronization module **500**, a quench waveform generator **506**, and a data detection module **510**. The timing synchronization module **500** includes a packet detection module **502**, a symbol synchronization module **504**, and a pulse synchronization module **508**.

The ADC **501** converts an incoming baseband signal from an analog form to a digital form. The packet detection module **502** continuously monitors a presence of data packets in the air based on an input signal received from the ADC **501**. When the transmitter **104** transmits a data packet in a form of the baseband signal, the receiver **102** determines a presence of the data packet based on the incoming baseband signal. Upon detecting the data packet, the symbol synchronization module **504** estimates a start index of the preamble signal corresponding to the detected data packet, and sets a starting point of a first symbol of the preamble signal based on the estimated start index. The pulse synchronization module **508** calculates a shift λ required in a quench waveform in order to synchronize a peak of each pulse of the preamble signal corresponding to the detected data packet with a sensitivity region of an SRR. In some embodiments, the generated quench waveform has an OQR equal to 1. Also, the pulse synchronization module **508** provides information required for synchronizing a peak of each pulse of the remaining incoming baseband signal with the quench waveform. The data detection module **510** processes the remaining baseband signal after the above-described synchronization and detects payload data in the data packet.

FIG. **6** is a flowchart **600** of a method to time synchronization in the receiver **102**, according to an embodiment. When the transmitter **104** transmits a baseband signal corresponding to a preamble signal to the receiver **102**, the receiver **102** synchronizes its timing with the transmitter **104** as described in operations **602** to **606**.

In operation **602**, the method detects an incoming data packet based on the baseband signal received from the transmitter **104**. The baseband signal corresponds to a data packet carrying the preamble signal transmitted by the transmitter **104**. The preamble signal includes at least one block of synchronization sequence, and each block of synchronization sequence includes a basic pulse sequence with an intermittent fractional shift αT_s of predetermined time duration between consecutive basic sequences. The basic sequences with the intermittent fractional shift of predetermined time duration enable the receiver **102** to detect an incoming data packet. The detailed process of detecting an incoming data packet is illustrated in FIG. **7**.

In operation **604**, the method estimates a start index of the preamble signal corresponding to the detected data packet, and a starting point of a first symbol of the preamble signal is set based on the estimated start index. When the data packet is detected, an index at which the data packet is detected is determined. Also, the method determines peaks existing around the index of the detected data packet. Based on the number of peaks, the method determines an index corresponding to the farthest peak around the index of the detected data packet as a start index of the preamble signal. Based on the start index, the method sets the starting point of the first symbol of the preamble signal. A detailed process of determining the start index of the preamble signal is illustrated in FIG. **8**.

In operation **606**, based on the starting point of the first symbol of the preamble signal, the method synchronizes a peak of each pulse of the preamble signal corresponding to the detected data packet with the sensitivity region of the receiver **102**. In some embodiments, the peak of each pulse is synchronized with the sensitivity region of the receiver **102**

by shifting the quench waveform from the starting point of the first symbol of the preamble signal such that the peak of each pulse falls within the sensitivity region of the receiver **102**. A detailed process of the above-described synchronization is illustrated in FIG. **9**.

FIG. **7** is a flowchart **700** of a method to detect an incoming data packet based on a baseband signal, according to an embodiment. In operation **702**, the method receives an incoming baseband signal. The baseband signal may correspond to a preamble signal transmitted from the transmitter **104**. The preamble signal includes at least one training sequence, and each training sequence includes at least one basic sequence. Each basic sequence includes at least one period P. In operation **704**, the method computes a normalized sliding correlation value by correlating the incoming baseband signal y(t) with a predetermined basic sequence x(t). In some embodiments, a single period of the basic sequence x(t) is correlated with the incoming baseband signal y(t) to obtain a correlation value. In these embodiments, a correlation value for a single period of the basic sequence is computed by Equation 1:

$$R_{xy}(\tau)=\frac{\frac{1}{L}\sum_{i=0}^{L-1}x(i)y(\tau+i)}{\sqrt{\frac{1}{L}\sum_{i=0}^{L-1}[x(i)-\bar{x}]^2}\sqrt{\frac{1}{L}\sum_{i=0}^{L-1}[y(\tau+i)-\bar{y}(\tau)]^2}} \quad \text{[Equation 1]}$$

where L is a length of the basic sequence, P is a period, and $\bar{x}$ and $\bar{y}$ satisfy:

$$\bar{x}=\frac{1}{L}\sum_{i=0}^{L-1}x(i) \quad \text{[Equation 1-1]}$$

and

$$\bar{y}(\tau)=\frac{1}{L}\sum_{i=0}^{L-1}y(\tau+i). \quad \text{[Equation 1-2]}$$

According to an embodiment, in order to reduce a probability of false alarm, the method detects the incoming data packet based on the baseband signal when the incoming signal satisfies Equation 1-3.

$$x(t)=x'(t),x'(t)\in[0,1] \quad \text{[Equation 1-3]}$$

If the preamble signal includes a basic sequence with a single period (i.e., P=1), the method obtains a single correlation value. However, when the preamble signal includes a basic sequence with more than one period, then the method computes a correlation value of each period in the basic sequence by using Equation 1. Also, the correlation values are averaged to obtain an average correlation value by Equation 2.

$$\bar{R}_{xy}(\tau)=\frac{1}{P}\sum_{i=0}^{P-1}R_{xy}(\tau+iL) \quad \text{[Equation 2]}$$

Furthermore, if the preamble signal includes a plurality of blocks of synchronization sequences, the method averages respective average correlation values of the plurality of blocks of synchronization sequences using Equations 3 and 3-1:

$$\bar{R}_{B,xy}(\tau)=\frac{1}{Z}\sum_{i=0}^{Z-1}\bar{R}_{xy}(\tau+i\chi) \quad \text{[Equation 3]}$$

$$\chi=Q(LP+1) \quad \text{[Equation 3-1]}$$

where Z is the number of basic sequences in the preamble signal.

In operation **706**, the method compares the correlation value R_{xy} with a predetermined threshold value T_p. The method computes the predetermined threshold value T_p based on a requisite probability of missed detection and a probability of false alarm. The method determines the predetermined threshold value T_p such that the predetermined threshold value T_p satisfies the probability of missed detection under a constraint on the probability of false alarm. For example, the method sets the predetermined threshold value T_p around 0.6 to 0.8.

In operation **708**, the method determines whether the correlation value R_{xy} is greater than or equal to the predetermined threshold value T_p. If the correlation value R_{xy} is greater than or equal to the predetermined threshold value T_p, at operation **710**, the method declares a data packet as detected.

FIG. **8** is a flowchart **800** of an exemplary method of setting a starting point of a preamble signal corresponding to a detected data packet, according to an embodiment. In operation **802**, the method detects a presence of an SFD sequence in an incoming baseband signal y(t) by correlating the incoming baseband signal y(t) and a predetermined SFD sequence s(t). In some embodiments, the incoming baseband signal y(t) is correlated with the predetermined SFD sequence s(t) by Equation 4.

$$R_{sy}(\tau)=\frac{\frac{1}{L_S}\sum_{i=0}^{L_S-1}s(i)y(i+\tau)}{\sqrt{\frac{1}{L_S}\sum_{i=0}^{L_S-1}[s(i)-\bar{s}]^2}\sqrt{\frac{1}{L_S}\sum_{i=0}^{L_S-1}[y(\tau+i)-\bar{y}(\tau)]^2}} \quad \text{[Equation 4]}$$

where L_s is a length of a predetermined SFD sequence s(i).

In operation **804**, the method determines whether a correlation value R_{sy} obtained from Equation 4 is greater than or equal to a predetermined threshold value T_f. The threshold value T_f is set such that the threshold value T_f satisfies the probability of missed detection under a constraint on the probability of false alarm. For example, the threshold value T_f is set around 0.7 to 0.8. If the correlation value R_{sy} is greater than or equal to the threshold value T_f, then the method would determine that the SFD sequence s(t) is present in the incoming baseband signal y(t). If the correlation value R_{sy} is smaller than the predetermined threshold value T_f, the method would determine that the SFD sequence s(t) is not present in the incoming baseband signal y(t).

If the SFD sequence s(t) is detected, at operation **806**, the method determines a symbol synchronization point is determined in operation **806**. In some embodiments, the symbol synchronization point may correspond to a point where the SFD sequence s(t) is detected in the incoming baseband signal y(t). If the SFD sequence s(t) is not detected, at operation **808**, the method determines an index value τ_p, corresponding to the correlation value R_{xy}. The correlation value R_{xy} is a value at which the incoming data packet is detected.

In operation **810**, the method computes a set of correlation values $\bar{R}_{xy}$ using the determined index value τ_p. The correlation values $\bar{R}_{xy}$ are computed by Equation 5:

$$\overline{R}_{xy}(\tau) = \frac{1}{P}\sum_{i=0}^{P-1} R_{xy}(\tau + iL) \quad \text{[Equation 5]}$$

For example, if a number of basic sequences (Q) is 3, the set of correlation values may be represent as the following set:

$$\{\overline{R}_{xy}(\tau_p-2(LP+1)),\overline{R}_{xy}(\tau_p-(LP+1)),\overline{R}_{xy}(\tau_p),\ \overline{R}_{xy}(\tau_p+(LP+1)),\overline{R}_{xy}(\tau_p+2(LP+1))\ \overline{R}_{xy}(\tau_p-2(LP+1)+1),\overline{R}_{xy}(\tau_p-(LP+1)+1),\overline{R}_{xy}(\tau_p),\ \overline{R}_{xy}(\tau_p+(LP+1)-1),\overline{R}_{xy}(\tau_p+2(LP+1)-1)\} \quad \text{[Equation 5-1]}$$

The set of correlation values may be generalized by Equation 5-2.

$$\overline{R}_{xy}=\{\overline{R}_{xy}(\tau_p+i(LP+1)-sgn(i)\times j)\},i\epsilon[-(Q-1),(Q-1)],j\epsilon[0,1] \quad \text{[Equation 5-2]}$$

In operation **812**, the method identifies at least one correlation value that is greater than or equal to a predetermined threshold value T_s from the set of correlation values. The threshold value T_s is selected such that the threshold value T_s satisfies the probability of missed detection under a constraint on the probability of false alarm. For example, the threshold value T_s is set around 0.4 to 0.8. In operation **814**, the method estimates a start index τ_s of the preamble signal based on the number of correlation values identified in operation **812**. The start index τ_s indicates a starting point of a first symbol of a preamble signal transmitted by the transmitter **104**. In operation **816**, the method sets the starting point of the first symbol of the preamble signal based on the start index τ_s of the preamble signal.

For example, in response to the number of correlation values being greater than or equal to the number of basic sequences (Q) in the preamble signal, the method sets the minimum value of the start index τ_s corresponding to the identified correlation values as the starting point of the first symbol of the preamble signal.

Alternatively, the method computes a difference of index values between a first correlation value and a second correlation value, and a difference of index values between a second correlation value and a third correlation value. If the differences of the index values are respectively equal to Q and Q+1, then the method computes a correlation value by correlating the incoming baseband signal y(t) with the predetermined SFD sequence s(t) shifted from the maximum index τ_{Pmax} of the at least one correlation value identified in operation **812** to around Q. For example, a correlation value is computed by Equation 6.

$$R_{sy}(\tau_{pmax}+LP) = \frac{\sum_{i=0}^{L_S-1} s(i)y(i+\tau_{pmax}+LP)}{\sqrt{\frac{1}{L_S}\sum_{i=0}^{L_S-1}[s(i)-\bar{s}]^2}\sqrt{\frac{1}{L_S}\sum_{i=0}^{L_S-1}[y(\tau_{pmax}+LP+i)-\bar{y}(\tau)]^2}} \quad \text{[Equation 6]}$$

Furthermore, a maximum correlation value R_{sy} is selected from correlation values obtained by Equation 6 and compared with the predetermined threshold value T_f. If the maximum correlation value R_{sy} exceeds the predetermined threshold value T_f, then the method offsets the starting point of the first symbol by an offset duration from the index corresponding to the maximum correlation value R_{sy}. The method computes the offset duration using Equation 7.

$$\tau_s=\tau_{SFD}-QLP-1 \quad \text{[Equation 7]}$$

where τ_{SFD} is an index value corresponding to a correlation value using which the SFD sequence s(t) is detected in the incoming baseband signal y(t).

The above-described process of estimating the starting point of the first symbol is generally applicable in cases where a low amplitude portion of a first period of the basic sequence of the preamble signal falls within the sensitivity region of the receiver **102**.

If the duration between successive correlation values is greater than Q+1, the method determines an index τ_s corresponding to the minimum value of successive correlation values as the starting point of the first symbol of the preamble signal. However, if the number of correlation values is less than the number of basic sequences (Q) of the preamble signal, the method computes the correlation value by correlating the incoming baseband signal y(t) with the predetermined SFD sequence s(t) shifted from the maximum index τ_{Pmax} of the correlation values identified in operation **812** by (L*P). For example, a maximum correlation value $R_{sy}(\tau_{Pmax}+LP)$ is computed by Equation 8.

$$R_{sy}(\tau_{pmax}+LP) = \frac{\frac{1}{L_S}\sum_{i=0}^{L_S-1} s(i)y(i+\tau_{pmax}+LP)}{\sqrt{\frac{1}{L_S}\sum_{i=0}^{L_S-1}[s(i)-\bar{s}]^2}\sqrt{\frac{1}{L_S}\sum_{i=0}^{L_S-1}[y(\tau+i)-\bar{y}(\tau)]^2}} \quad \text{[Equation 8]}$$

Furthermore, the maximum correlation value $R_{sy}(\tau_{Pmax}+LP)$ is compared with the predetermined threshold value T_f. If the correlation value $R_{sy}(\tau_{Pmax}+LP)$ exceeds the predetermined threshold value T_f, then the starting point τ_s of the first symbol is computed by Equation 9.

$$\tau_s=\tau_{pmax}-2(LP+1) \quad \text{[Equation 9]}$$

If the maximum correlation value $R_{sy}(\tau_{Pmax}+LP)$ is smaller than the predetermined threshold value T_f, the method selects the index τ_s of the minimum value of the correlation values as the starting point of the first symbol of the preamble signal. If the number of identified correlation value $R_{sy}(\tau_{Pmax}+LP)$ is equal to 1, the method considers the index τ_s corresponding to the identified correlation value $R_{sy}(\tau_{Pmax}+LP)$ as the starting point of the first symbol of the preamble signal.

Once the starting point of the preamble signal is set as the start index τ_s, the incoming baseband signal with the set starting point of the preamble signal $y_s(t)$ is provided to the pulse synchronization module **508** so as to synchronize a peak of each pulse of the preamble signal with the sensitivity region of the receiver **102** as described below.

FIG. **9** is a flowchart **900** of a method to synchronize the peak of each pulse of the preamble signal corresponding to the detected data packet with the sensitivity region of the receiver **102**, according to an embodiment. In operation **902**, the method determines a status of a pulse synchronization flag. During estimation of the start index τ_s of the preamble signal, the pulse synchronization flag is set to 0 or 1. When the pulse synchronization flag is 0, the pulse synchronization flag indicates that synchronization of the peak of each pulse with the sensitivity region of the receiver **102** needs to be performed. On the other hand, when the pulse synchronization flag is 1, the synchronization of the peak of each pulse is not to be performed. For example, the method sets the pulse synchronization flag to 1 when low amplitude portions of the first period fall within the sensitivity region of the receiver **102**. Also, the pulse synchronization flag is set to 1 when the

number of correlation values is less than Q−1 and the maximum value of the correlation values is greater than the predetermined threshold value T_f.

In operation **904**, the method determines whether the pulse synchronization flag is set to 1. If the pulse synchronization flag is set to 1. Then, in operation **906**, the method shifts a quench waveform of the receiver **102** by duration equal to $T_s/2$ and processes the incoming data packet based on the shifted quench waveform.

If the pulse synchronization flag is set to 0, then in operation **908**, the method obtains an average sample corresponding to each period of the basic sequence of the preamble signal. For example, if the basic sequence has 3 periods (i.e., P=3), then an average sample S_λ that corresponds to the 3 periods is computed by Equations 10 to 12.

$$S_\lambda(1) = \frac{1}{LP}\sum_{i=0}^{LP-1} y_s(i) \quad \text{[Equation 10]}$$

$$S_\lambda(2) = \sum_{i=LP+1}^{2LP} y_s(i) \quad \text{[Equation 11]}$$

$$S_\lambda(3) = \frac{1}{L}\sum_{i=2(LP+1)}^{3LP+1} y_s(i) \quad \text{[Equation 12]}$$

Alternatively, the method computes the average samples $S_\lambda(1)$, $S_\lambda(2)$, and $S_\lambda(3)$ with respect to is in the basic sequences of the preamble signal by Equations 10 to 12.

In operation **910**, the method computes a pulse offset error metric β_λ using the obtained average samples. For example, the method computes the pulse offset error metric using Equation 13.

$$\beta_\lambda = \frac{S_\lambda(1) - S_\lambda(3)}{S_\lambda(2)} \quad \text{[Equation 13]}$$

In operation **912**, the method estimates a shift λ required in the quench waveform with respect to the starting point of the first symbol of the preamble signal using the pulse offset error metric β_λ. In some embodiments, the method estimates the shift λ required in the quench waveform corresponding to the pulse offset error metric β_λ using a lookup table. The lookup table includes N values of the pulse offset error metric β_λ and the shift λ required in the quench waveform corresponding to the pulse offset error metric β_λ varies from 0 to T.

In operation **914**, the method synchronizes the peak of each pulse of the preamble signal with the sensitivity region of the receiver **102** by shifting the quench waveform from the starting point of the first symbol of the preamble signal by the determined shift λ. Consequently, the sensitivity region of the quench waveform is aligned with the peak of each pulse of the incoming baseband signal in order to maximize the regenerative gain. This is possible due to the addition of the intermittent fractional shifts αT_s and βT_s in the preamble signal because different portions of the incoming baseband signal fall within the sensitivity region of the receiver **102** during different portions of the preamble signal. Once the peak of each pulse is synchronized, the method feeds again the quench waveform and the incoming baseband signal for further processing.

The value of λ computed in operation **912** may be applicable when the number of basic sequences (Q) in a block of synchronization sequence is less than or equal to 3. However, when Q>3, a fractional shift λ or T_{foff} required in the quench waveform with respect to the starting point of the first symbol of the preamble signal is estimated by Equation 14.

$$\lambda = \left[\frac{N_{max}}{LP}\right]\alpha T_S \quad \text{[Equation 14]}$$

where N_{max} is an index corresponding to the maximum correlation value obtained from the set of correlation values greater than the predetermined threshold value T_s identified in operation **812** of FIG. **8**.

FIGS. **10**A and **10**B are schematic diagrams **1000** and **1050** illustrating synchronization of the peak of each of the preamble signal with the sensitivity region of the quench waveform. In FIG. **10**A, the schematic diagram **1000** illustrates a correlation between an incoming baseband signal **1004** corresponding to a preamble signal, and a quench waveform **1002** having an OQR equal to 1. The incoming baseband signal **1004** includes an intermittent fractional shift **1006** between basic sequences of the preamble signal. Also, the quench waveform **1002** has a sensitivity region **1008** away from the peak of each pulse of the incoming baseband signal **1004**.

Referring to FIG. **10**B, the schematic diagram **1050** illustrates shifting of the quench waveform **1002** to synchronize the peak of each pulse of the preamble signal by a shift duration **1052** from a start index **1054**. By shifting the quench waveform by the shift duration **1052**, the peak of each pulse of the preamble signal synchronized with the sensitivity region of the receiver **102** is indicated by a reference numeral **1056**.

FIG. **11** is a block diagram of an SRR, according to an embodiment. The SRR **1100** is an embodiment of the receiver **102** of FIG. **1**. The SRR **1100** includes an antenna **1102**, a low noise amplifier (LNA) **1104**, a super regenerative oscillator (SRO) **1108**, an envelope detector (ED) **1108**, a low pass filter (LPF) **1110**, the ADC **501**, the timing synchronization module **500**, the quench waveform generator **506**, and the data detection module **510**.

As shown in FIG. **11**, the timing synchronization module **500** connected to the ADC **501** detects a data packet in the air corresponding to a preamble signal, determines a start index of the preamble signal, and computes a shift in quench waveform so as to synchronize a peak of each pulse of an incoming baseband signal corresponding to the preamble signal with a sensitivity region of the SRR. A start index and a shift in the quench waveform are provided to the quench waveform generator **506** so that the SRO **1106** synchronizes the peak of each pulse of the remaining incoming baseband signal with the sensitivity region of the quench waveform. The components of the SRR **1100**, such as the antenna **1102**, the LNA **1104**, the SRO **1106**, the ED **1108**, and the LPF **1100**, are well-known to one of ordinary skill in the art and hence the description thereof will be omitted.

The elements described herein, for example, in FIGS. **2**, **5**, and **11**, may be implemented using hardware components. The hardware components may include, for example, controllers, sensors, processors, generators, drivers, and other equivalent electronic components. The hardware components may be implemented using one or more general-purpose or special purpose computers, such as, for example, a processor, a controller and an arithmetic logic unit, a digital signal processor, a microcomputer, a field programmable array, a programmable logic unit, a microprocessor or any other device capable of responding to and executing instructions in a defined manner. The hardware components may run an

operating system (OS) and one or more software applications that run on the OS. The hardware components also may access, store, manipulate, process, and create data in response to execution of the software. For purpose of simplicity, the description of a processing device is used as singular; however, one skilled in the art will appreciated that a processing device may include multiple processing elements and multiple types of processing elements. For example, a hardware component may include multiple processors or a processor and a controller. In addition, different processing configurations are possible, such a parallel processors.

It is to be understood that in the embodiment of the present invention, the operations in FIGS. **3** and **6-9** are performed in the sequence and manner as shown although the order of some operations and the like may be changed without departing from the spirit and scope of the described configurations. In accordance with an illustrative example, a computer program embodied on a non-transitory computer-readable medium may also be provided, encoding instructions to perform at least the method described in FIGS. **3** and **6-9**.

Program instructions to perform a method described in FIGS. **3** and **6-9**, or one or more operations thereof, may be recorded, stored, or fixed in one or more computer-readable storage media. The program instructions may be implemented by a computer. For example, the computer may cause a processor to execute the program instructions. The media may include, alone or in combination with the program instructions, data files, data structures, and the like. Examples of computer-readable media include magnetic media, such as hard disks, floppy disks, and magnetic tape; optical media such as CD ROM disks and DVDs; magneto-optical media, such as optical disks; and hardware devices that are specially configured to store and perform program instructions, such as read-only memory (ROM), random access memory (RAM), flash memory, and the like. Examples of program instructions include machine code, such as produced by a compiler, and files containing higher level code that may be executed by the computer using an interpreter. The program instructions, that is, software, may be distributed over network coupled computer systems so that the software is stored and executed in a distributed fashion. For example, the software and data may be stored by one or more computer readable recording mediums. Also, functional programs, codes, and code segments for accomplishing the example embodiments disclosed herein may be easily construed by programmers skilled in the art to which the embodiments pertain based on and using the flow diagrams and block diagrams of the figures and their corresponding descriptions as provided herein.

A number of examples have been described above. Nevertheless, it will be understood that various modifications may be made. For example, suitable results may be achieved if the described techniques are performed in a different order and/or if components in a described system, architecture, device, or circuit are combined in a different manner and/or replaced or supplemented by other components or their equivalents. Accordingly, other implementations are within the scope of the following claims.

What is claimed is:

1. A method, comprising:

generating a preamble signal, wherein a peak of each pulse of the preamble signal is synchronized with a sensitivity region of a super regenerative receiver (SRR); and

transmitting, to the SRR, a data packet comprising the preamble signal, wherein the data packet is a baseband signal corresponding to the preamble signal,

wherein the preamble signal comprises blocks of synchronization sequences, each of the blocks of synchronization sequences comprising basic sequences with an intermittent fractional shift of a time duration between consecutive basic sequences.

2. The method of claim **1**, wherein the generating of the preamble signal comprises:

generating a basic binary sequence,

repeating the generated basic binary sequence for a number of times,

converting the repetitive basic binary sequences into repetitive basic pulse sequences,

adding a first intermittent fractional shift between basic pulse sequences to obtain a block of synchronization sequence,

repeating the block of synchronization sequences for a number of times, and

adding a second intermittent fractional shift between blocks of synchronization sequences.

3. A method of operating a super regenerative receiver (SRR), the method comprising:

detecting a data packet based on a baseband signal corresponding to a preamble signal received from a transmitter;

setting a starting point of a first symbol of the preamble signal corresponding to the detected data packet; and

synchronizing a peak of each pulse of the preamble signal with a sensitivity region of the SRR by shifting a quench waveform from the starting point of the first symbol of the preamble signal by an estimated shift.

4. The method of claim **3**, wherein the detecting of the incoming data packet comprises:

computing a correlation value by correlating the baseband signal with a basic sequence,

comparing the computed correlation value and a threshold value and outputting a comparison result, and

detecting the data packet based on the comparison result.

5. The method of claim **4**, wherein the computing of the correlation value comprises:

computing a correlation value for each period in a basic sequence of the preamble signal, and

computing an average correlation value by averaging the computed correlation values corresponding to the periods in the basic sequence.

6. The method of claim **3**, wherein the setting of the starting point comprises:

detecting a start frame delimiter (SFD) sequence of the baseband signal by computing a correlation value between the baseband signal and a SFD sequence, and

determining a symbol synchronization point by comparing the computed correlation value and a threshold value.

7. The method of claim **6**, wherein the setting of the starting point further comprises:

determining, according to a comparison between the computed correlation value and the threshold value, an index value corresponding to a correlation value obtained by correlating the baseband signal with a basic sequence,

computing a set of correlation values using the index value,

identifying, from the computed set of correlation values, a correlation value that is greater than or equal to a threshold value, and

estimating a start index of the preamble signal based on a number of identified correlation values,

wherein the starting point of the first symbol of the preamble signal is set based on the estimated start index.

8. The method of claim **3**, wherein the synchronizing of the peak of each pulse of the preamble signal comprises:

determining a status of a pulse synchronization flag, and

processing, based on the status of the pulse synchronization flag, the data packet remaining after shifting a quench waveform by a period.

9. The method of claim **8**, wherein the synchronizing of the peak of each pulse of the preamble signal further comprises:

obtaining an average sample for each of basic sequences of the preamble signal based on the status of the pulse synchronization flag,

computing a pulse offset error metric using the obtained average samples, and

estimating, based on the computed pulse offset error metric, a shift required in the quench waveform with respect to a start index of the preamble signal in order to synchronize the peak of each pulse of the preamble signal with the sensitivity region of the SRR,

wherein the peak of each pulse of the preamble signal is synchronized with the sensitivity region of the SRR based on the estimated shift.

10. The method of claim **7**, wherein the synchronizing of the peak of each pulse of the preamble signal comprises:

identifying an index corresponding to a maximum correlation value from among the identified correlation values, and

estimating, based on the identified index, a shift required in a quench waveform with respect to a start index of the preamble signal in order to synchronize the peak of each pulse of the preamble signal with the sensitivity region of the SRR,

wherein the peak of each pulse of the preamble signal is synchronized with the sensitivity region of the SRR based on the estimated shift.

11. An apparatus, comprising:

a preamble signal generation module configured to generate a preamble signal, wherein a peak of each pulse of the preamble signal is synchronized with a sensitivity region of a super regenerative receiver (SRR); and

a transmitter configured to transmit, to the SRR, a data packet that comprises the preamble signal and is in a form of a baseband signal corresponding to the generated preamble signal,

wherein the preamble signal comprises blocks of synchronization sequences, each of the blocks of synchronization sequences comprising basic sequences with an intermittent fractional shift of a time duration between consecutive basic sequences.

12. The apparatus of claim **11**, wherein the preamble signal generation module is configured to:

generate a basic binary sequence,

repeat the basic binary sequence for a number of times,

convert the repetitive basic binary sequences into repetitive basic pulse sequences,

add a first intermittent fractional shift between basic pulse sequences to obtain a block of synchronization sequences,

repeat the block of synchronization sequences for a number of times, and

add a second intermittent fractional shift between blocks of synchronization sequences.

13. A super regenerative receiver (SRR), comprising:

a packet detection module configured to detect a data packet based on a baseband signal corresponding to a preamble signal received;

a symbol synchronization module configured to set a starting point of a first symbol of the preamble signal corresponding to the detected data packet; and

a pulse synchronization module configured to synchronize a peak of each pulse of the preamble signal with a sensitivity region of the SRR by shifting a quench waveform from the starting point of the first symbol of the preamble signal by an estimated shift.

14. The SRR of claim **13**, wherein the packet detection module is configured to:

compute a correlation value by correlating the baseband signal with a basic sequence,

compare the computed correlation value and a threshold value, and

detect the data packet based on a comparison result.

15. The SRR of claim **14**, wherein the packet detection module is configured to:

compute a correlation value for each period in a basic sequence of the preamble signal, and

compute an average correlation value by averaging the computed correlation values corresponding to the periods in the basic sequence.

16. The SRR of claim **13**, wherein the symbol synchronization module is configured to:

detect a start frame delimiter (SFD) sequence of the baseband signal by computing a correlation value between the baseband signal and a SFD sequence, and

determine a symbol synchronization point by comparing the correlation value and a threshold value.

17. The SRR of claim **16**, wherein the symbol synchronization module is configured to:

determine, according to a comparison between the computed correlation value and the predetermined threshold value, an index value corresponding to a correlation value obtained by correlating the baseband signal with a basic sequence,

compute a set of correlation values by using the index value,

identify, from the set of correlation values, a correlation value that is greater than or equal to a threshold value,

estimate a start index of the preamble signal based on a number of identified correlation values, and

set the starting point of the first symbol of the preamble signal based on the estimated start index.

18. The SRR of claim **13**, wherein the pulse synchronization module is configured to:

determine a status of a pulse synchronization flag, and

process, based on the status of the pulse synchronization flag, the data packet remaining after shifting a quench waveform by a period.

19. The SRR of claim **18**, wherein the pulse synchronization module is configured to:

obtain an average sample for each of basic sequences of the preamble signal based on the status of the pulse synchronization flag,

compute a pulse offset error metric by using the obtained average samples,

estimate, based on the computed pulse offset error metric, a shift required in the quench waveform with respect to a start index of the preamble signal in order to synchronize the peak of each pulse of the preamble signal with the sensitivity region of the SRR, and

synchronize the peak of each pulse of the preamble signal with the sensitivity region of the SRR based on the estimated shift.

20. The SRR of claim **17**, wherein the pulse synchronization module is configured to:

identify an index corresponding to a maximum correlation value from among the identified correlation values,

estimate, based on the identified index, a shift required in a quench waveform with respect to a start index of the

preamble signal in order to synchronize the peak of each pulse of the preamble signal with the sensitivity region of the SRR, and

synchronize the peak of each pulse of the preamble signal with the sensitivity region of the SRR based on the estimated shift.

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